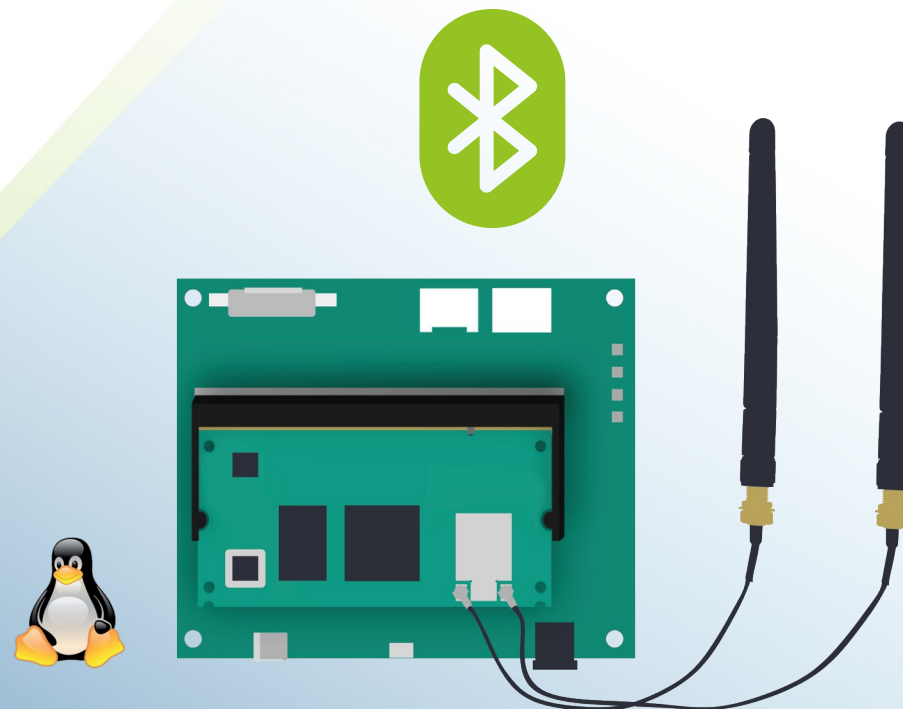


Bluetooth on Embedded Linux Systems Deep Dive

Presented by
Toradex



WITH YOU TODAY...

- Joined Toradex 2011, leaving this June
- Spearheaded Embedded Linux Adoption
- Introduced Upstream First Policy
- Top 10 U-Boot Contributor
- Top 10 Linux Kernel Arm SoC Contributor
- Industrial Embedded Linux Platform Torizon Fully Based on Mainline Technology
 - Mainline U-Boot with Distroboot
 - KMS/DRM Graphics with Etnaviv & Nouveau
 - OTA with OSTree
 - Docker resp. Podman



Marcel Ziswiler

Platform Manager - Embedded Linux BSP
Toradex

WHAT WE'LL COVER TODAY...

- Introduction to Bluetooth
- Bluetooth Specifications
- Bluetooth Security
- Bluetooth Low Energy (BLE) vs. Bluetooth (Classic)
- Bluetooth Protocol Stack
- BlueZ
- Linux Kernel Bluetooth Controller Drivers
- Embedded Linux Integration
- BlueALSA
- PipeWire/WirePlumber
- Bluetooth Debugging
- Live Demo



Introduction to Bluetooth[®]

- Has short-range, is low-cost and easy-to-use
- Operates within unlicensed industrial, scientific, and medical (ISM) 2.402 GHz to 2.48 GHz radio band
- Uses Frequency-Hopping Spread Spectrum (FHSS)
- Usually performs 1600 hops per second with Adaptive Frequency-Hopping (AFH, avoids crowded frequencies) enabled
- Divides transmitted data into packets
- Transmits each packet on one of 79 designated Bluetooth channels
- Each channel has 1 MHz bandwidth
- Gaussian Frequency-Shift Keying (GFSK) modulation in basic rate (BR) mode
- Bluetooth 2.0+EDR introduced Enhanced Data Rate modes
- Differential Quadrature Phase-Shift Keying ($\pi/4$ -DQPSK) modulation in EDR2 transferring 2 Mbit/s
- 8-DPSK modulation in EDR3 transferring 3 Mbit/s
- Usually fabricated as RF CMOS integrated circuits

Introduction to Bluetooth (cont.)

- Standard wire-replacement communications protocol
- Low power consumption
- Ad-hoc connection
- Voice and data transfer
- Wireless Personal Area Network (WPAN)
- Employs UHF radio waves
- Class 2 devices
 - Transmission power limited to 2.5 milliwatts
 - Range of up to 10 Meters (33 Feet)
- But range depends on
 - Air and obstacles in between
 - Data rate
 - Protocol (classic or low energy)
 - Transmission power
 - Receiver sensitivity
 - Relative orientations and gains of both antennas

Bluetooth device power by class

Class	Maximum permitted power	
	mW	dBm
1	10 to 100	+10 to +20
1.5	2.5 to 10	+4 to +10
2	1 to 2.5	0 to +4
3	0.01 to 1	-20 to 0

Bluetooth History

- Development of "short-link" radio technology initiated in 1989 by Ericsson Mobile in Lund, Sweden
- Principal design and development began in 1994
- By 1997 team had a workable solution
- IBM collaborating on integrating mobile phone into ThinkPad notebook but power consumption deemed too high
- Instead agreed to integrate Ericsson's short-link technology
- Neither of the two were market share leaders in their respective markets at that time
- Agreed to make short-link technology an open industry standard to permit each player maximum market access
- Ericsson contributed short-link radio technology, IBM contributed patents around logical layer
- Recruited Intel to join who also recruited Toshiba and Nokia
- In 1998 Bluetooth SIG launched with total of five members: Ericsson, IBM, Intel, Nokia, and Toshiba
- In 1999 first device to market hands-free mobile headset earned "Best of show Technology Award" at COMDEX
- First Bluetooth mobile phone was Ericsson T36, revised Ericsson T39 actually made it to store shelves in 2001
- Name Bluetooth initially only intended as codename
- In 2012 Jaap Haartsen of Ericsson was nominated by the European Patent Office for the European Inventor Award

Bluetooth Special Interest Group (SIG)

- Not-for-profit
- Non-stock corporation
- Standards organization
- More than 35'000 member companies
- Oversees development of specification
- Manages qualification program
- Protects trademarks
- Network of applicable patents
- Licensed to individual qualifying devices

Bluetooth Specifications

- Bluetooth 1.0 and 1.0B
 - Products were not interoperable
- Bluetooth 1.1
 - Ratified as IEEE 802.15.1-2002
 - Fixed errors as found in v1.0B spec
 - Possibility of non-encrypted channels
 - Received signal strength indicator (RSSI)
- Bluetooth 1.2
 - Faster connection and discovery
 - Adaptive Frequency-Hopping (AFH) spread spectrum improving resistance to radio frequency interference
 - Higher transmission speed up to 721 kbit/s
 - Extended Synchronous Connections (eSCO) improving voice quality of audio links
 - Host Controller Interface (HCI) operation with three-wire UART
 - Ratified as IEEE 802.15.1-2005 but no longer maintained
 - L2CAP with flow control and 2 transmission modes

Bluetooth Specifications (cont.)

- Bluetooth 2.0 + EDR (before 2005)
 - Optional Enhanced Data Rate (EDR) with up to 3 Mbit/s
- Bluetooth 2.1 + EDR (26 July 2007)
 - Secure Simple Pairing (SSP)
 - Extended Inquiry Response (EIR) which allows better filtering
- Bluetooth 3.0 + HS (21 April 2009)
 - L2CAP Enhanced Retransmission Mode (ERTM) reliable vs. Streaming Mode (SM) unreliable channels
 - Alternative MAC/PHY (AMP) 802.11 aka Wi-Fi with up to 24 Mbit/s
 - AMP originally intended for Ultra-Wideband (UWB) whose development later got suspended
 - Low latency unicast connectionless data for small amounts of data
 - Closed loop enhanced power control
- Bluetooth 4.0 (Bluetooth Smart, 30 June 2010)
 - Bluetooth Low Energy (BLE formerly Wibree) as entirely new protocol stack
 - Very low power applications e.g. powered by coin-cell
 - Security Manager (SM) services with AES encryption

Bluetooth Specifications (cont.)

- Bluetooth 4.1 (4 December 2013)
 - Coexistence signaling
 - Low duty cycle directed advertising
 - L2CAP connection-oriented dedicated channels with credit-based flow control
 - Dual mode and topology
 - Audio architecture updates for wide band speech
 - Fast data advertising interval
 - Limited discovery time
- Bluetooth 4.2 (2 December 2014)
 - Low energy secure connection with data packet length extension
 - Link layer privacy with extended scanner filter policies
 - Internet Protocol Support Profile (IPSP) version 6 ready for Bluetooth Smart things to support connected home

Bluetooth Specifications (cont.)

- Bluetooth 5 (6 December 2016)
 - Slot Availability Mask (SAM)
 - 2 Mbit/s LE PHY
 - LE long range
 - High duty cycle non-connectable advertising
 - LE advertising extensions
 - LE channel selection algorithm #2
 - Higher output power
 - Removed park state feature
- Bluetooth 5.1 (21 January 2019)
 - Angle of Arrival (AoA) and Angle of Departure (AoD) used for device locating and tracking
 - Advertising channel index
 - GATT caching
 - Periodic advertising sync transfer
 - Removed unit keys feature

Bluetooth Specifications (cont.)

- Bluetooth 5.2 (31 December 2019)
 - Enhanced Attribute Protocol (EATT)
 - LE power control
 - LE isochronous channels
 - LE audio using LC3 codec
- Bluetooth 5.3 (13 July 2021)
 - Connection subrating
 - Periodic advertisement interval
 - Channel classification enhancement
 - Encryption key size control enhancements
 - Removed Alternative MAC and PHY (AMP) extension
- Bluetooth 5.4 (7 February 2023)
 - Periodic Advertising with Responses (PawR)
 - Encrypted advertising data
 - LE GATT security levels characteristic
 - Advertising coding selection

Bluetooth Security

- Bluetooth technology may be fairly secure
- However, many (older) devices rely on short or even fixed numeric personal identification numbers (PINs) instead of more secure passwords or passphrases
- Bluetooth v2.1 addressed some of the earlier security concerns e.g. by introducing Secure Simple Pairing (SSP)
- Disable Bluetooth when not in use
- Use "hidden" aka not "discoverable" mode once "paired"
- Link key storage: on the device file system vs. Bluetooth chip itself (e.g. on removable devices)
- Denial of Service (DoS) by sending rapid unsolicited pairing requests
- Bluesnarfing: Using Bluetooth connection to steal information
- Bluejacking: Sending picture or message to unsuspecting user via Bluetooth
- Recent (2023) yet unpatched vulnerabilities: Bluetooth Low Energy Forward and Future Secrecy Attacks (BLUFFS)

Bluetooth Low Energy (BLE) vs. Bluetooth (Classic)

- Introduced in specification 4.0
- New basically incompatible protocol stack
- Very low power consumption
- 40 channels of 2 MHz (vs. 79 channels of 1 MHz)
- 24-bit CRC (vs. 8- or 16-bit CRC)
- Unlimited number of active slaves (vs. only 7 active slaves)
- Lower cost
- Maintaining similar communication range
- Initially 500 kbps (vs. 1 Mbps BR or 2-3 Mbps EDR), but Bluetooth 5 LE also 2 Mbps
- Dual-mode or single-mode implementations
- Lightweight link layer providing ultra-low power idle mode operation

Bluetooth Protocol Stack

- Link Manager
 - Establishing connection between devices
 - Link authentication and configuration
 - Management protocol
 - Using services in Link Controller (LC)
 - Supported services
 - Data transmission and reception
 - Name request
 - Request link address
 - Connection establishment
 - Authentication
 - Link mode negotiation
- Host Controller Interface (HCI)
 - Command interface between controller and host

Bluetooth Protocol Stack (cont.)

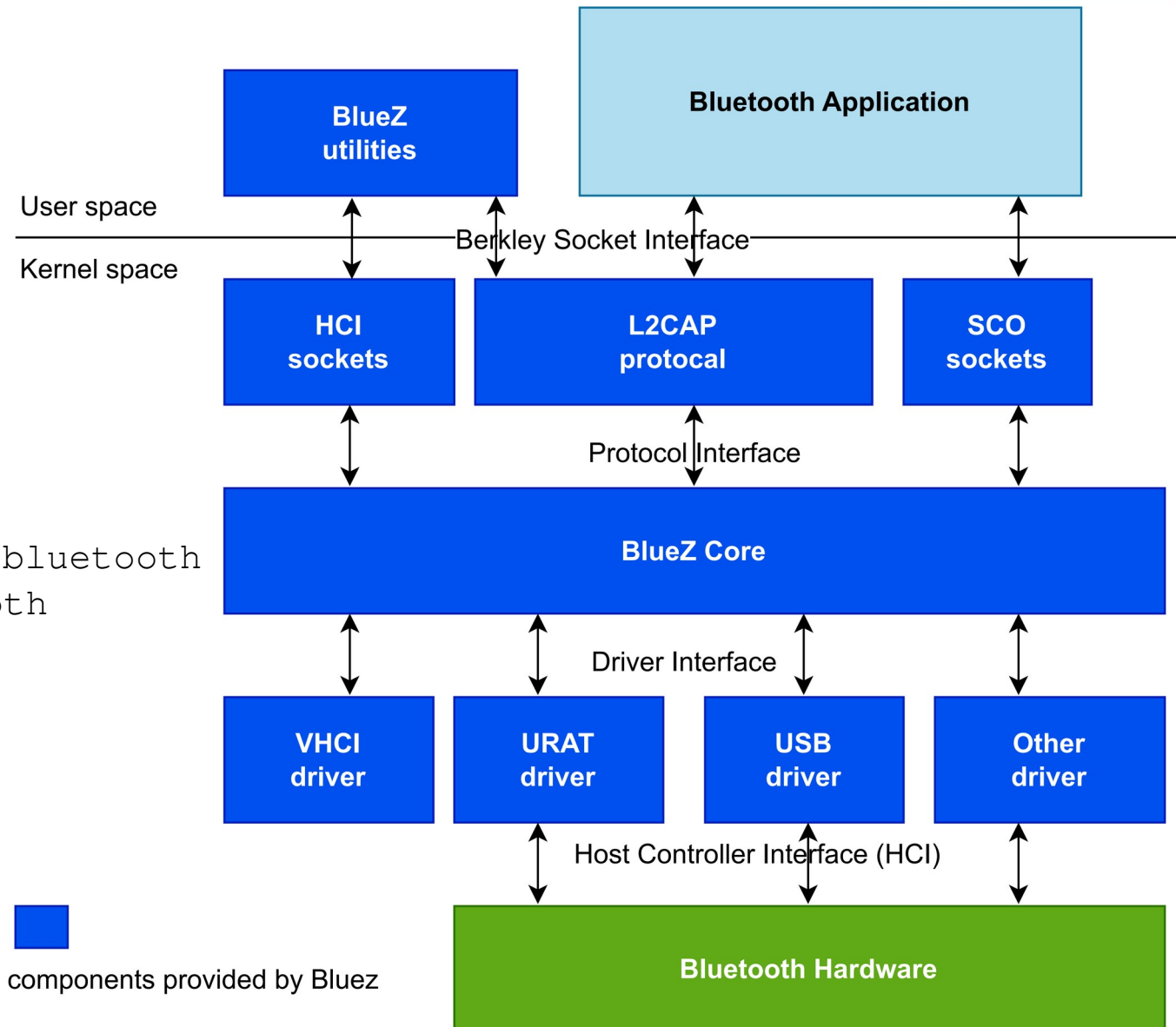
- Logical Link Control and Adaption Protocol (L2CAP)
 - Multiplex multiple logical connections
 - Segmentation and reassembly of on-air packets
 - Basic mode payload of up to 64 KB, 672 bytes default MTU (48 bytes mandatory minimum)
 - Retransmission and flow control modes
Configurable for isochronous data or reliable data with retransmission and CRC per channel
 - Enhanced Retransmission Mode (ERTM) providing reliable L2CAP channel
 - Streaming Mode (SM) without retransmission or flow control providing unreliable L2CAP channel
 - Reliability optionally and/or additionally guaranteed by lower layer BDR/EDR air interface
(configurable number of retransmissions and flush timeout with guaranteed in-order sequencing)
 - Only L2CAP channels configured in ERTM or SM may be operated over AMP logical links
- Service Discovery Protocol (SDP)
 - Discover services offered by other devices and their associated parameters
- Radio Frequency Communications (RFCOMM)
 - Cable replacement protocol emulating EIA-232 (formerly RS-232) serial port
 - Simple reliable data stream

Bluetooth Protocol Stack (cont.)

- Bluetooth Network Encapsulation Protocol (BNEP)
 - Transferring another protocol stack's data via L2CAP channel
 - Main purpose transmission of IP packets in personal area networking profile
- Audio/Video Control Transport Protocol (AVCTP)
 - Used by remote control profile to transfer AV/C commands over L2CAP channel
- Audio/Video Distribution Transport Protocol (AVDTP)
 - Used by Advanced Audio Distribution (A2DP) profile to stream music over L2CAP channel
- Telephony Control Protocol - Binary (TCS BIN)
 - Bit-oriented protocol for call control signaling
 - Cordless telephony profile failed to attract implementers, therefore of historical interest only
- Many adopted protocols defined by other standards
 - Point-to-Point Protocol (PPP)
 - TCP/IP, UDP
 - Object Exchange Protocol (OBEX) from IrDA
 - Wireless Application Environment/Wireless Application Protocol (WAE/WAP)

Linux Bluetooth Protocol Stack - BlueZ

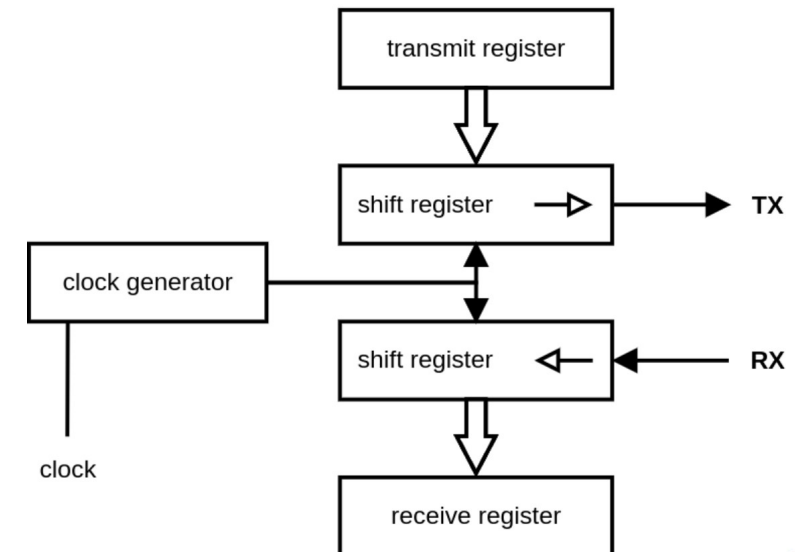
- Since 2006
- Originally developed by Qualcomm
- Android relies on Fluoride (formerly Bluedroid) which is a different stack originally developed by Broadcom
- User-space daemons and utilities
- Linux kernel Bluetooth subsystem `net/bluetooth` and accompanying `drivers/bluetooth` since version 2.6



Linux Kernel Bluetooth Controller Drivers



- Interfaces/Protocols
 - HCI SDIO driver (BT_HCIBTSDIO)
 - HCI UART driver (BT_HCIUART) with the following protocol support
 - Broadcom (BT_HCIUART_BCM)
 - H4 (BT_HCIUART_H4)
 - H5 (three-wire, BT_HCIUART_3WIRE, still relevant for TI CC2564 et. al.)
 - HCILL (HCI Low Level for Texas Instruments' BRF chips (still relevant for WiLink 8 WL18xx, BT_HCIUART_LL)
 - Intel (BT_HCIUART_INTEL)
 - Marvell (BT_HCIUART_MRVL)
 - Qualcomm Atheros (BT_HCIUART_QCA)
 - Realtek (BT_HCIUART_RTL)



Linux Kernel Bluetooth Controller Drivers (cont.)

- Interfaces/Protocols (cont.)
 - HCI USB driver (BT_HCIBTUSB) with following protocol support
 - Broadcom (BT_HCIBTUSB_BCM)
 - MediaTek (BT_HCIBTUSB_MTK)
 - Realtek (BT_HCIBTUSB_RTL)
 - Marvell Bluetooth driver (BT_MRVL, BT_MRVL_SDIO) support for 8688/8787/8797/8887/8897/8977/8987/8997
 - MediaTek HCI SDIO driver (BT_MTKSDIO)
 - MediaTek HCI UART driver (BT_MTKUART)
 - Qualcomm SMD based HCI support (BT_QCOMSMD)
 - NXP protocol support (BT_NXPUART)

Linux Kernel Bluetooth Controller Drivers (cont.)

- Obsolete
 - UART Nokia H4+ protocol support (`BT_HCIUART_NOKIA`) first available 2009 (N900) resp. until 2011 (N950)
 - BCSP (BlueCore Serial) protocol support (`BT_HCIUART_BCSP`) for non USB Bluetooth devices based on CSR BlueCore chip (later bought by Qualcomm) e.g. BlueCore 5 BC67E Bluetooth 3 or CSR8510 Bluetooth 4.0, latest CSR101x Series Bluetooth 4.1
 - Atheros AR300x serial support (`BT_HCIUART_ATH3K`) for Atheros AR3011/AR3012 Bluetooth chipsets Bluetooth 3.0/4.0
 - Intel AG6XX (`BT_HCIUART_AG6XX`) for Intel/Infineon AG620 modem available 2014/2016
 - HCI BCM203x USB driver
 - HCI BPA10x USB driver (`BT_HCIBPA10X`) for Digianswer (later Tektronix resp. Teledyne LeCroy) BPA 100/105 Bluetooth sniffer available 2002
 - HCI BlueFRITZ! USB driver (`BT_HCIBFUSB`) first available 2004, now obsolete
 - Various obsolete PC Card drivers (`BT_HCIDTL1`, `BT_HCIBT3C`, `BT_HCIBLUECARD`, ...)
 - Atheros firmware download driver (`BT_ATH3K`)
 - Redpine BT driver (`BT_HCIRSI`) for Redpine RSI_91x later acquired by Silicon Labs

Linux Kernel Bluetooth Controller Drivers (cont.)

- Vendors which have upstream driver support
 - Broadcom (nowadays Infinium, formerly Cypress, and Synaptics)
 - Intel
 - MediaTek
 - NXP (formerly Marvell)
 - Qualcomm
 - Realtek



Broadcom

- SparkLAN (AMPAK) AP6275P Synaptics SYN43752 or Ezurio (formerly Laird) Sona IF573 Infineon AIROC CYW55573

- Bluetooth 5.3 or 5.4 via UART
- Wi-Fi 6 or 6E via PCIe (not covered)
- M.2 2230 form f., key E (also avail. as M.2 1216)
- Linux driver: `drivers/bluetooth/btbcm.c/h`
- Kernel configuration: `CONFIG_BT_BCM`
- Firmware: `brcm/BCM4362A2.hcd`
- Module parameters: N/A



```
[ 9.135073] Bluetooth: Core ver 2.22
[ 9.139102] NET: Registered PF_BLUETOOTH protocol family
[ 9.147569] Bluetooth: HCI device and connection manager initialized
[ 9.170605] Bluetooth: HCI socket layer initialized
[ 9.178587] Bluetooth: L2CAP socket layer initialized
[ 9.190844] Bluetooth: SCO socket layer initialized
[ 9.567938] Bluetooth: HCI UART driver ver 2.3
[ 9.811811] Bluetooth: HCI UART protocol Broadcom registered
[ 9.820699] hci_uart_bcm serial0-0: supply vbat not found, using dummy regulator
[ 9.844431] hci_uart_bcm serial0-0: supply vddio not found, using dummy regulator
[ 9.858853] hci_uart_bcm serial0-0: No reset resource, using default baud rate
[10.232034] Bluetooth: hci0: BCM: chip id 159
[10.239424] Bluetooth: hci0: BCM: features 0x0f
[10.267633] Bluetooth: hci0: BCM4362A2
[10.271535] Bluetooth: hci0: BCM4362A2 (000.017.017) build 0000
[10.277644] Bluetooth: hci0: BCM: firmware Patch file not found, tried:
[10.284325] Bluetooth: hci0: BCM: 'brcm/BCM4362A2.fsl,imx8mp-evk.hcd'
[10.290822] Bluetooth: hci0: BCM: 'brcm/BCM4362A2.hcd'
[10.298814] Bluetooth: hci0: BCM: 'brcm/BCM.fsl,imx8mp-evk.hcd'
[10.307616] Bluetooth: hci0: BCM: 'brcm/BCM.hcd'
[11.191550] Bluetooth: MGMT ver 1.22
root@imx8mpevk:~# hciconfig -a
hci0:   Type: Primary   Bus: UART
        BD Address: 00:0E:8E:B2:48:FF  ACL MTU: 1021:8  SCO MTU: 64:1
        UP RUNNING
        RX bytes:3003 acl:0 sco:0 events:109 errors:0
        TX bytes:1934 acl:0 sco:0 commands:96 errors:0
        Features: 0xbf 0xfe 0xcf 0xfe 0xdb 0xff 0x7b 0x87
        Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
        Link policy: RSWITCH SNIFF
        Link mode: PERIPHERAL ACCEPT
        Name: 'imx8mpevk'
        Class: 0x000000
        Service Classes: Unspecified
        Device Class: Miscellaneous,
        HCI Version: 5.0 (0x9)  Revision: 0x0
        LMP Version: 5.0 (0x9)  Subversion: 0x1111
        Manufacturer: Broadcom Corporation (15)
```

- AX210NGW or BE200NGW
 - Bluetooth 5.3 or 5.4 via USB 2.0
 - Wi-Fi 6E or 7 via PCIe (not covered)
 - M.2 2230 form f., key A+E resp. key E (or M.2 1216)
 - Linux driver: `drivers/bluetooth/btintel.c/h`
 - Kernel configuration: `CONFIG_BT_INTEL`
 - Firmware: `intel/ibt-0041-0041.sfi`,
`ibt-0041-0041.ddc`, `ibt-0291-0291.sfi`,
`ibt-0291-0291.ddc`



Module
params:
N/A

```
[ 5.247700] Bluetooth: Core ver 2.22
[ 5.257542] Bluetooth: HCI device and connection manager initialized
[ 5.264544] Bluetooth: HCI socket layer initialized
[ 5.272268] Bluetooth: L2CAP socket layer initialized
[ 5.280121] Bluetooth: SCO socket layer initialized
[ 5.312953] Bluetooth: hci0: Device revision is 0
[ 5.321250] Bluetooth: hci0: Secure boot is enabled
[ 5.326245] Bluetooth: hci0: OTP lock is enabled
[ 5.331014] Bluetooth: hci0: API lock is enabled
[ 5.335682] Bluetooth: hci0: Debug lock is disabled
[ 5.340679] Bluetooth: hci0: Minimum firmware build 1 week 10 2014
[ 5.347080] Bluetooth: hci0: Bootloader timestamp 2019.40 buildtype 1 build 38
[ 5.364686] Bluetooth: hci0: Found device firmware: intel/ibt-0041-0041.sfi
[ 5.372060] Bluetooth: hci0: Boot Address: 0x100800
[ 5.376986] Bluetooth: hci0: Firmware Version: 60-48.23
[ 6.789266] Bluetooth: hci0: Waiting for firmware download to complete
[ 6.795897] Bluetooth: hci0: Firmware loaded in 1390722 usecs
[ 6.801850] Bluetooth: hci0: Waiting for device to boot
[ 6.826943] Bluetooth: hci0: Device booted in 24570 usecs
[ 6.833018] Bluetooth: hci0: Found Intel DDC parameters: intel/ibt-0041-0041.ddc
[ 6.843248] Bluetooth: hci0: Applying Intel DDC parameters completed
[ 6.850988] Bluetooth: hci0: No support for BT device in ACPI firmware
[10.906939] Bluetooth: hci0: Firmware timestamp 2023.48 buildtype 1 build 75324
[10.938993] Bluetooth: hci0: Firmware SHA1: 0x23bac558
[11.117401] Bluetooth: MGMT ver 1.22
root@verdin-imx8mp-07106916:~# hciconfig -a
hci0:   Type: Primary  Bus: USB
        BD Address: 70:A8:D3:54:2C:B5  ACL MTU: 1021:4  SCO MTU: 96:6
        UP RUNNING
        RX bytes:985 acl:0 sco:0 events:68 errors:0
        TX bytes:1596 acl:0 sco:0 commands:68 errors:0
        Features: 0xbf 0xfe 0x0f 0xfe 0xdb 0xff 0x7b 0x87
        Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
        Link policy: RSWITCH SNIFF
        Link mode: PERIPHERAL ACCEPT
        Name: 'verdin-imx8mp-07106916'
        Class: 0x0c0000
        Service Classes: Rendering, Capturing
        Device Class: Miscellaneous,
        HCI Version: 5.3 (0xc)  Revision: 0x363c
        LMP Version: 5.3 (0xc)  Subversion: 0x363c
        Manufacturer: Intel Corp. (2)
```


- MT7922 (Filologic 330) or MT7925 (Filologic 360)
- Bluetooth 5.2 or dual 5.4 via USB 2.0
- Wi-Fi 6E or 7 via PCIe (not covered)
- M.2 2230 form factor, key A+E resp. key E (also available as M.2 1216)
- Firmware:
mediatek/BT_RAM_CODE_MT7922_1_1_hdr.bin
mediatek/mt7925/BT_RAM_CODE_MT7925_1_1_hdr.bin
- Linux driver: `drivers/bluetooth/btmtk.c/h`
- Kernel configuration: `CONFIG_BT_MTK`
- Module parameters: N/A



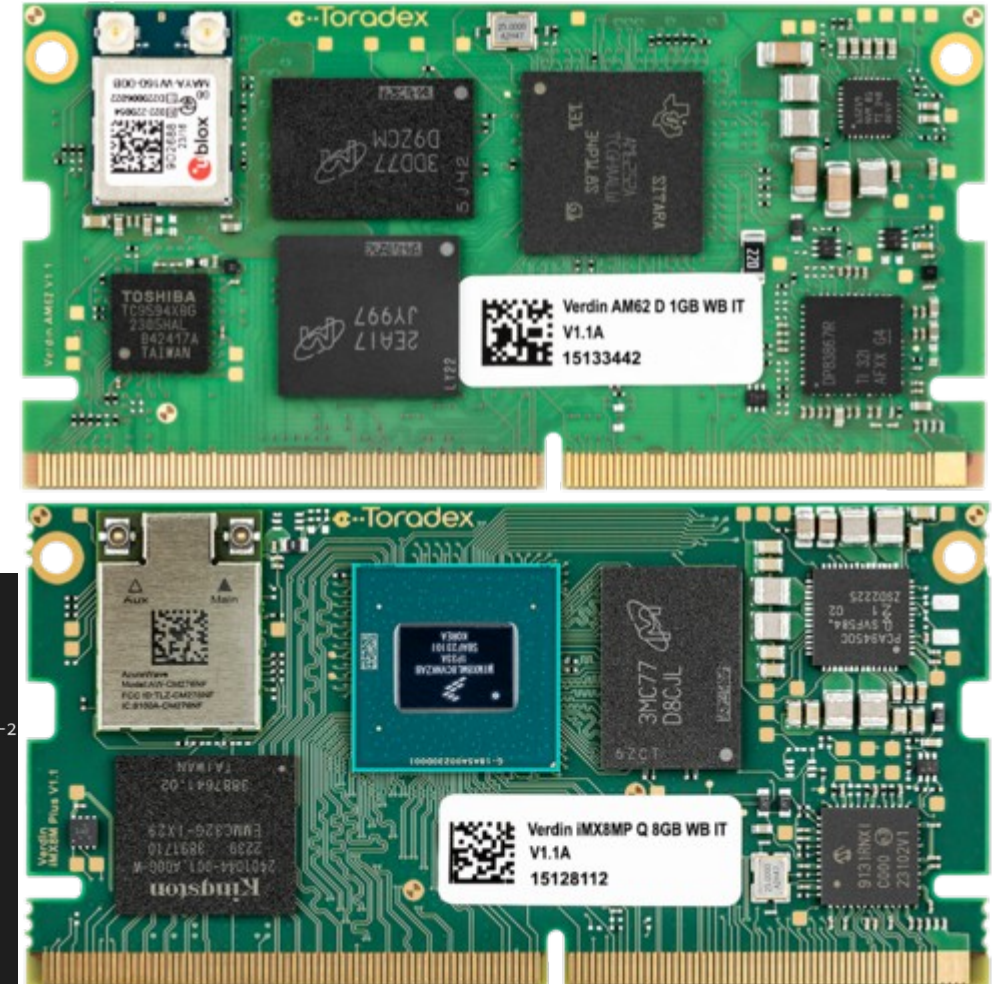
```
5.409299] Bluetooth: Core ver 2.22
[ 5.414126] NET: Registered PF_BLUETOOTH protocol family
[ 5.421555] Bluetooth: HCI device and connection manager initialized
[ 5.430662] Bluetooth: HCI socket layer initialized
[ 5.435794] Bluetooth: L2CAP socket layer initialized
[ 5.440933] Bluetooth: SCO socket layer initialized
[ 5.457288] usbcore: registered new interface driver btusb
[ 5.471544] Bluetooth: hci0: HW/SW Version: 0x008a008a, Build Time: 20231120183620
[ 7.873954] Bluetooth: hci0: Device setup in 2356946 usecs
[ 7.879549] Bluetooth: hci0: HCI Enhanced Setup Synchronous Connection command is advertised, but not supported.
[ 8.001793] Bluetooth: MGMT ver 1.22
root@verdin-imx8mp-07106916:~# hciconfig -a
hci0: Type: Primary Bus: USB
      BD Address: B4:8C:9D:02:1F:3A ACL MTU: 1021:6 SCO MTU: 240:8
      UP RUNNING
      RX bytes:1818 acl:0 sco:0 events:83 errors:0
      TX bytes:1725 acl:0 sco:0 commands:70 errors:0
      Features: 0xbf 0x3e 0x8d 0xfe 0xdb 0xff 0x7b 0x87
      Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
      Link policy: RSWITCH SNIFF
      Link mode: PERIPHERAL ACCEPT
      Name: 'verdin-imx8mp-07106916'
      Class: 0x0c0000
      Service Classes: Rendering, Capturing
      Device Class: Miscellaneous,
      HCI Version: 5.2 (0xb) Revision: 0x2018
      LMP Version: 5.2 (0xb) Subversion: 0x2311
      Manufacturer: MediaTek, Inc. (70)
```

- Verdin AM62 with IW416 u-blox Maya-W1 or Verdin iMX8M Plus with 88W8997 AzureWave AW-CM276NF

- Bluetooth 5.3 via UART
- Wi-Fi 4 or 5 via SDIO (not covered)
- u-blox proprietary Maya or M.2 1216
- Linux driver: `drivers/bluetooth/btnxpuart.c/h`
- Kernel configuration: `CONFIG_BT_NXPUART`
- Firmware: `nxp/uartiw416_bt_v0.bin`,
`nxp/uartuart8997_bt_v4.bin`

- Module
params:
N/A

```
[ 8.854765] Bluetooth: Core ver 2.22
[ 8.861503] NET: Registered PF_BLUETOOTH protocol family
[ 8.869005] Bluetooth: HCI device and connection manager initialized
[ 8.879378] Bluetooth: HCI socket layer initialized
[ 8.885807] Bluetooth: L2CAP socket layer initialized
[ 8.894659] Bluetooth: SCO socket layer initialized
[ 11.558768] bluetooth hci0: Direct firmware load for nxp/uartiw416_bt_v0.bin failed with error -2
[ 11.572960] Bluetooth: hci0: Firmware file nxp/uartiw416_bt_v0.bin not found
[ 74.234947] Bluetooth: MGMT ver 1.22
root@verdin-am62-15133499:~# hciconfig -a
hci0: Type: Primary Bus: UART
      BD Address: 6C:1D:EB:9D:3E:2C ACL MTU: 1021:7 SCO MTU: 120:6
      UP RUNNING
      RX bytes:856 acl:0 sco:0 events:58 errors:0
      TX bytes:1560 acl:0 sco:0 commands:58 errors:0
      Features: 0xbf 0xfe 0x8f 0xfe 0xdb 0xff 0x7b 0x87
      Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
      Link policy: RSWITCH SNIFF
      Link mode: PERIPHERAL ACCEPT
      Name: 'verdin-am62-15133499'
      Class: 0x0c0000
      Service Classes: Rendering, Capturing
      Device Class: Miscellaneous,
      HCI Version: (0xc) Revision: 0x8300
      LMP Version: (0xc) Subversion: 0x1054
      Manufacturer: Marvell Technology Group Ltd. (72)
```



Qualcomm

- QCNFA765 or QCNCM865
 - Bluetooth 5.3 or 5.4 via USB
 - Wi-Fi 6E or 7 via PCIe (not covered)
 - M.2 2230 form factor, key E
 - Linux driver: `drivers/bluetooth/btqca.c/h`
 - Kernel configuration: `CONFIG_BT_QCA`
 - Firmware: `qca/rampatch_usb_00130200.bin`, `qca/rampatch_usb_00130201.bin` and `qca/nvm_usb_00130201_gf.bin`
 - Module parameters: N/A



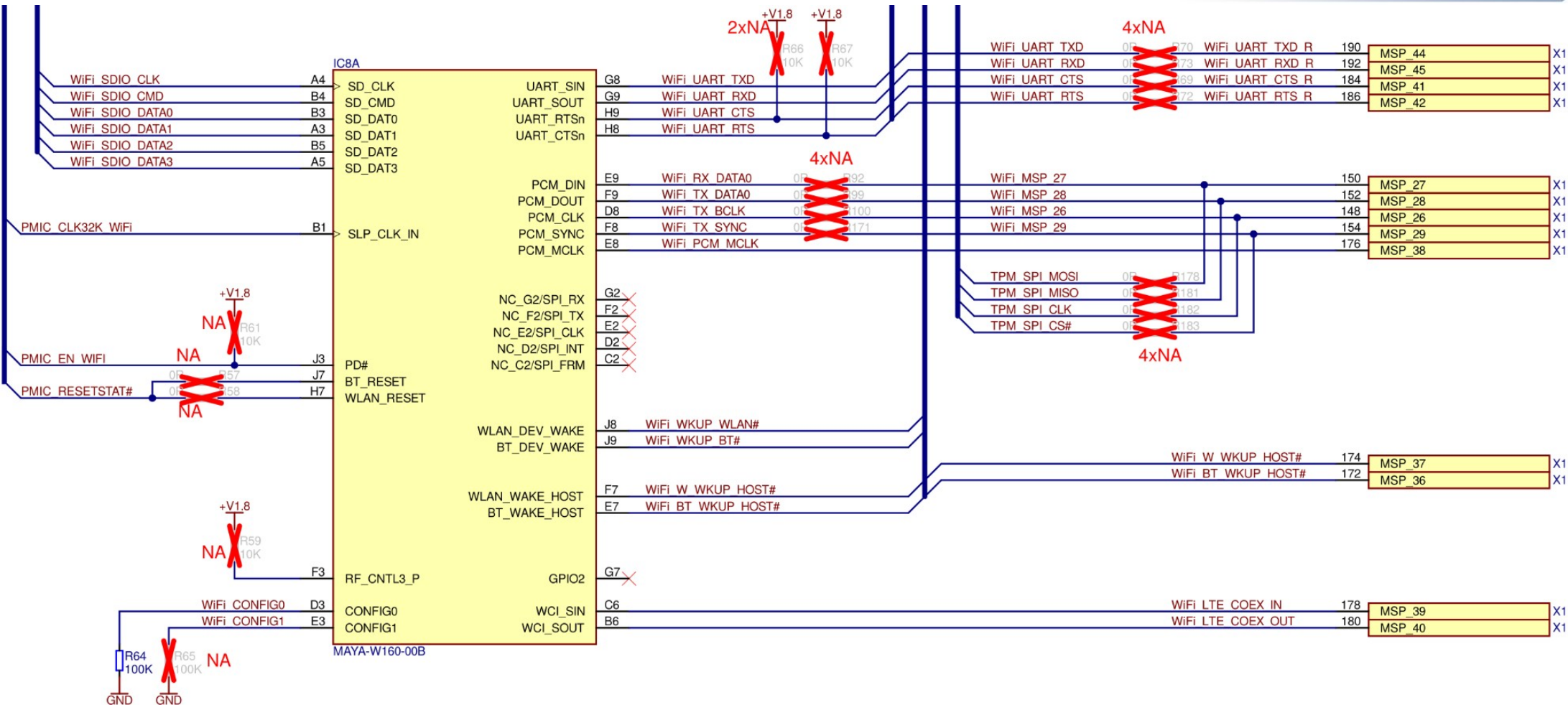
```
[ 6.364586] Bluetooth: Core ver 2.22
[ 6.477425] Bluetooth: HCI device and connection manager initialized
[ 6.502120] Bluetooth: HCI socket layer initialized
[ 6.513323] Bluetooth: L2CAP socket layer initialized
[ 6.518628] Bluetooth: SCO socket layer initialized
[ 6.867378] Bluetooth: hci0: using rampatch file: qca/rampatch_usb_00130201.bin
[ 6.874721] Bluetooth: hci0: QCA: patch rome 0x130201 build 0x65e2, firmware rome 0x130201 build 0x38e6
[ 8.825513] Bluetooth: MGMT ver 1.22
[ 8.948969] Bluetooth: RFCOMM socket layer initialized
[ 8.958067] Bluetooth: RFCOMM ver 1.11
[ 9.869110] Bluetooth: hci0: using NVM file: qca/nvm_usb_00130201_gf.bin
[ 10.019100] Bluetooth: hci0: HCI Enhanced Setup Synchronous Connection command is advertised, but not supported.
[ 10.121344] Bluetooth: MGMT ver 1.22
root@verdin-imx8mp-07106916:~# hciconfig -a
hci0:   Type: Primary  Bus: USB
        BD Address: 44:C3:06:70:05:70  ACL MTU: 1024:7  SCO MTU: 240:8
        UP RUNNING
        RX bytes:1769 acl:0 sco:0 events:127 errors:0
        TX bytes:1502 acl:0 sco:0 commands:127 errors:0
        Features: 0xff 0xfe 0x8f 0xfe 0xd8 0x3f 0x7b 0x87
        Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
        Link policy: RSWITCH HOLD SNIFF
        Link mode: PERIPHERAL ACCEPT
        Name: 'verdin-imx8mp-07106916 #1'
        Class: 0x2c0000
        Service Classes: Rendering, Capturing, Audio
        Device Class: Miscellaneous,
        HCI Version: 5.3 (0xc)  Revision: 0x0
        LMP Version: 5.3 (0xc)  Subversion: 0x65e2
        Manufacturer: Qualcomm (29)
```

- RTL8852CE or RTL8952A
 - Bluetooth 5.3 or 5.4 via USB 2.0
 - Wi-Fi 6E or 7 via PCIe (not covered)
 - M.2 2230 form factor, key A+E resp. key E (also available as M.2 1216)
 - Linux driver: `drivers/bluetooth/btrtl.c/h`
 - Kernel configuration: `CONFIG_BT_RTL`
 - Firmware:
`rtl_bt/rtl8852cu_fw_v2.bin`,
`rtl_bt/rtl8852cu_config.bin`
 - Module parameters: N/A



```
[ 5.357703] Bluetooth: Core ver 2.22
[ 5.367133] Bluetooth: HCI device and connection manager initialized
[ 5.376120] Bluetooth: HCI socket layer initialized
[ 5.383906] Bluetooth: L2CAP socket layer initialized
[ 5.391690] Bluetooth: SCO socket layer initialized
[ 5.420212] Bluetooth: hci0: RTL: examining hci_ver=0c hci_rev=000c lmp_ver=0c lmp_subver=8852
[ 5.430152] Bluetooth: hci0: RTL: rom_version status=0 version=1
[ 5.438035] Bluetooth: hci0: RTL: loading rtl_bt/rtl8852cu_fw_v2.bin
[ 5.449680] Bluetooth: hci0: RTL: loading rtl_bt/rtl8852cu_config.bin
[ 5.458230] Bluetooth: hci0: RTL: cfg_sz 6, total sz 71983
[ 5.861166] Bluetooth: hci0: RTL: fw version 0x040d7225
[ 8.873534] Bluetooth: MGMT ver 1.22
root@verdin-imx8mp-07106916:~# hciconfig -a
hci0:   Type: Primary   Bus: USB
        BD Address: 38:B8:00:D0:AA:92  ACL MTU: 1021:8  SCO MTU: 255:12
        UP RUNNING
        RX bytes:2869 acl:0 sco:0 events:352 errors:0
        TX bytes:74714 acl:0 sco:0 commands:352 errors:0
        Features: 0xff 0xff 0xff 0xfe 0xdb 0xfd 0x7b 0x87
        Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
        Link policy: RSWITCH HOLD SNIFF PARK
        Link mode: PERIPHERAL ACCEPT
        Name: 'verdin-imx8mp-07106916 #1'
        Class: 0x0c0000
        Service Classes: Rendering, Capturing
        Device Class: Miscellaneous,
        HCI Version: 5.3 (0xc)  Revision: 0x40d
        LMP Version: 5.3 (0xc)  Subversion: 0x7225
        Manufacturer: Realtek Semiconductor Corporation (93)
```

Embedded Linux Integration



CONFIG[1:0]	Wi-Fi	Bluetooth
00	Reserved	Reserved
01	Reserved	Reserved
10	SDIO	UART
11	Reserved	Reserved

Embedded Linux Integration (cont.)

- Bluetooth interface:
 - SDIO
 - Often multi-function aka shared with e.g. Wi-Fi
 - UART
 - Usually RX/TX and RTS/CTS in our case `UART_SIN`, `UART_SOUT`, `UART_RTSn`, `UART_CTSn`
 - USB
 - Remember my talk in Prague from last year ;-p)
- Bluetooth audio: `PCM_*` would require custom firmware
- Control signals
 - Power
 - `PD#` connected to `PMIC_EN_WIFI` aka a GPIO
 - Reset
 - `BT_RESET`, `WLAN_RESET` a N/C in our case
 - Strapping
 - `CONFIG0`, `CONFIG1` configures e.g. what/where the bootROM expects to load the firmware from

Embedded Linux Integration (cont.)

- Control signals (cont.)
 - Wake signals
 - Host to device
 - `WLAN_DEV_WAKE` connected to `WIFI_WKUP_WLAN#`
 - `BT_DEV_WAKE` connected to `WIFI_WKUP_BT#`
 - Device to host
 - `WLAN_WAKE_HOST` connected to `WIFI_W_WKUP_HOST#`
 - `BT_WAKE_HOST` connected to `WIFI_BT_WKUP_HOST#`
 - Co-existence
 - `WCI_SIN, WCI_SOUT` connected to `WIFI_LTE_COEX_IN, WIFI_LTE_COEX_OUT`
- How does all this translate to devicetree?

Embedded Linux Integration (cont.)

```
• arch/arm64/boot/dts/ti/k3-am62-verdin-wifi.dtsi
• / {
•     wifi_pwrseq: wifi-pwrseq {
•         compatible = "mmc-pwrseq-simple";
•         pinctrl-names = "default";
•         pinctrl-0 = <&pinctrl_wifi_en>;
•         reset-gpios = <&main_gpio0 22 GPIO_ACTIVE_LOW>;
•     };
• };
• /* On-module Wi-Fi */
• &sdhci2 {
•     pinctrl-names = "default";
•     pinctrl-0 = <&pinctrl_sdhci2>;
•     bus-width = <4>;
•     cap-power-off-card;
•     keep-power-in-suspend;
•     mmc-pwrseq = <&wifi_pwrseq>;
•     non-removable;
•     ti,fails-without-test-cd;
•     vmmc-supply = <&reg_3v3>;
•     status = "okay";
• };
```


Embedded Linux Integration (cont.)

- `arch/arm64/boot/dts/ti/k3-am62-verdin-wifi.dtsi (cont.)`
- `/* On-module Bluetooth */`
- `&main_uart5 {`
- `pinctrl-names = "default";`
- `pinctrl-0 = <&pinctrl_uart5>;`
- `uart-has-rtscts;`
- `status = "okay";`
- `bluetooth {`
- `compatible = "nxp,88w8987-bt";`
- `fw-init-baudrate = <3000000>;`
- `};`
- `};`

Embedded Linux Integration (cont.)

- Firmware loading
 - Dedicated (e.g. each Bluetooth and Wi-Fi load their separate firmware)
 - Issue of shared control/power signals
 - Combined aka combo firmware
 - Use of faster interface e.g. SDIO to load entire firmware
 - Issue of driver load order (UART module loaded first would expect having to load its own firmware)
 - Can be worked around with `/etc/modprobe.d/btnxpuart.conf`

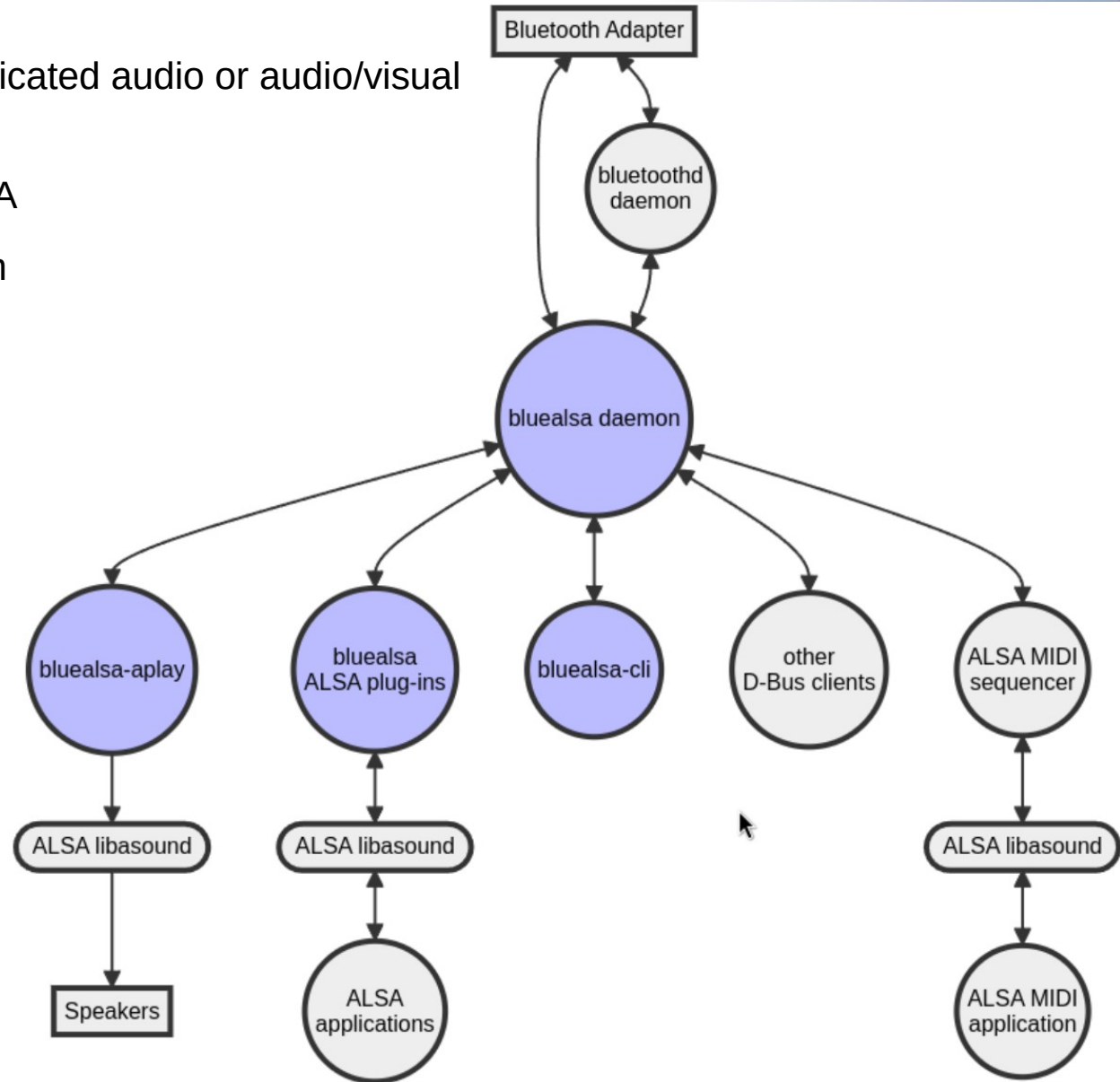
```
install btnxpuart /sbin/modprobe mwifiex_sdio; sleep 1; /sbin/modprobe --ignore-  
install btnxpuart
```

BlueALSA - Bluetooth Audio ALSA Backend

- Rebirth of direct integration between BlueZ and ALSA
- BlueZ version 5 dropped such support in favour of 3rd party audio applications
- BlueZ acts as middleware between audio application implementing Bluetooth audio profile and Bluetooth audio device
- Status quo alternative is full-blown general-purpose audio server like PipeWire (or former PulseAudio)
- Achieve same Bluetooth audio profile support as formerly with PulseAudio
- Fewer dependencies
- At a lower level in the software stack
- Registers all known Bluetooth audio profiles in BlueZ
- In theory any Bluetooth device with audio capabilities can be connected

BlueALSA Architecture

- Designed for use on small, low-powered, dedicated audio or audio/visual aka embedded systems
- Audio applications interface directly with ALSA
- Exclusive use of each Bluetooth audio stream
- Constrained by capabilities of ALSA API
- bluealsa daemon
 - Heart of BlueALSA
 - Handles profile connection and configuration
 - Presents audio streams via D-Bus
- ALSA plug-ins
 - Hide D-Bus specifics
 - Permit use of PCM and mixer interfaces
 - Seamless ALSA/BLE MIDI handling
- Utilities



BlueALSA Usage

- bluealsa daemon
 - Registers org.bluealsa D-Bus service
 - Handles pairing, connection and using remote Bluetooth audio devices
- Rely on regular high-level Linux Bluetooth pairing and connection procedure e.g. `bluetoothctl scan/pair/connect`
- ALSA plug-ins
 - Create virtual ALSA PCM device once Bluetooth audio device is connected
 - Usable from any ALSA application just like any other PCM device e.g. `aplay -D bluealsa:<optional BT address>`
 - Based on ALSA software PCM I/O plug-in
 - No associated sound card
 - Not available via ALSA kernel proc interface
 - Supports playback and capture e.g. `arecord -D bluealsa`
- A2DP profile for high quality audio
- HSP/HFP profiles via SCO link
 - Phone audio connection, but only audio related part
 - Optional oFono integration for full call feature support

PipeWire

- BlueZ integration via PipeWire's libspa-bluez5 (SPA means Simple Plugin API)
- Specific configuration format
 - Look-up order
 - `$XDG_CONFIG_HOME/pipewire/`
environment variable, often `~/.config/pipewire/` in distributions
 - `$sysconfdir/pipewire/`
compile-time variable, often `/etc/pipewire/`
 - `$datadir/pipewire/`
compile-time variable, often `/usr/share/pipewire/`
 - Plus config sections from similar `*conf.d` locations
- `context.spa-libs` maps plugin features with globs to a SPA library
- Defines shared object to be used to implement given factories
`context.spa-libs = {`
 - `# <factory-name regex> = <library-name>`
 - `# Maps a SPA factory to its parent library.`
 - `api.bluez5.* = bluez5/libspa-bluez5``}`

PipeWire Tooling

- PIPEWIRE_DEBUG
 - Environment variable allows overwriting log.level from config file
 - Allows increasing verbosity
 - Careful setting it higher than 3 aka Informational as it may cause underruns
- pw-config allows dumping config file related stuff
 - pw-config paths/list lists config paths resp. details all config sections
- pw-dump prints graph in JSON representation, rather verbose, often using pw-cli more appropriate
- pw-cli main command-line interface
 - Command and interactive mode
 - help lists all available commands
 - pw-cli ls/info <filter>
- pw-top good to get a quick overview
- pw-profiler allow profiling running nodes
- pw-mon monitors and dumps various events like e.g. adding/removing Bluetooth audio device

- Session and policy manager on top of PipeWire
- Modular approach with Lua engine
- By default replicates former PulseAudio behaviour aka desktop setup
- Enumerates and adds device objects for ALSA, BlueZ etc. and puts them into best-guess profile
- Two default nodes
 - Audio/Sink for playback
 - Audio/Source for capture
- Similar config look-up logic as PipeWire
- By default three config files: bluetooth.lua, main.lua and policy.lua
- Permission management
 - Property pipewire.access = “unrestricted”
- wpctl status

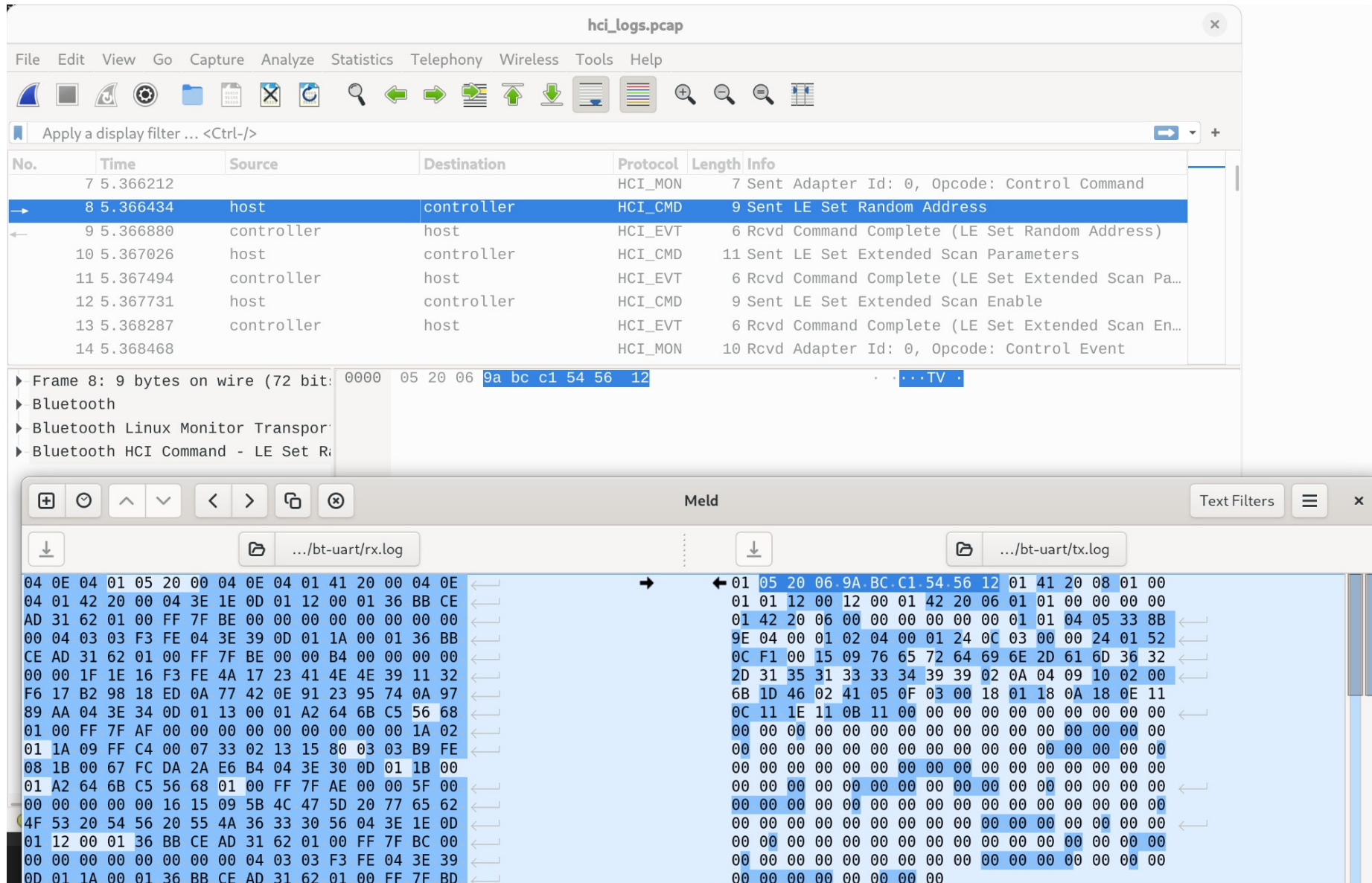
Yocto Project Build

- Put the following into your conf/local.conf
 - `LICENSE_FLAGS_ACCEPTED = "commercial"`
 - `PACKAGECONFIG:append:pn-pipewire = " bluez-aac bluez-opus bluez-lc3"`
 - `IMAGE_INSTALL:append = " wireplumber"`
 - `IMAGE_INSTALL:remove = "bluealsa"`
 - `OE_TERMINAL = "screen"`
 - `ACCEPT_FSL_EULA = "1"`
 - `DISTRO = "tdx-xwayland-upstream"`
- Build your image
 - `MACHINE=verdin-imx8mp bitbake -k tdx-reference-multimedia-image`

Bluetooth Debugging

- Find a good reproduction scenario using automated testing, scripting, etc.
- Figuring out where in the stack things go wrong
 - Low-level firmware/hardware: check UART or USB communication using logic/protocol analyser
 - Don't forget control signals: power-enable resp. disable, etc.
 - Analyse HCI communication using btmon available in BlueZ
 - Writes to file as well as standard out which is rather inconvenient also for live run-time use
 - Wireshark can visualise btmon traces

Bluetooth Debugging (cont.)



The image displays two windows used for Bluetooth debugging: Wireshark and Meld.

Wireshark Window (hci_logs.pcap):

- Menu: File, Edit, View, Go, Capture, Analyze, Statistics, Telephony, Wireless, Tools, Help
- Toolbar: Includes icons for capture, analysis, and navigation.
- Filter: Apply a display filter ... <Ctrl-/>
- Table of captured packets:

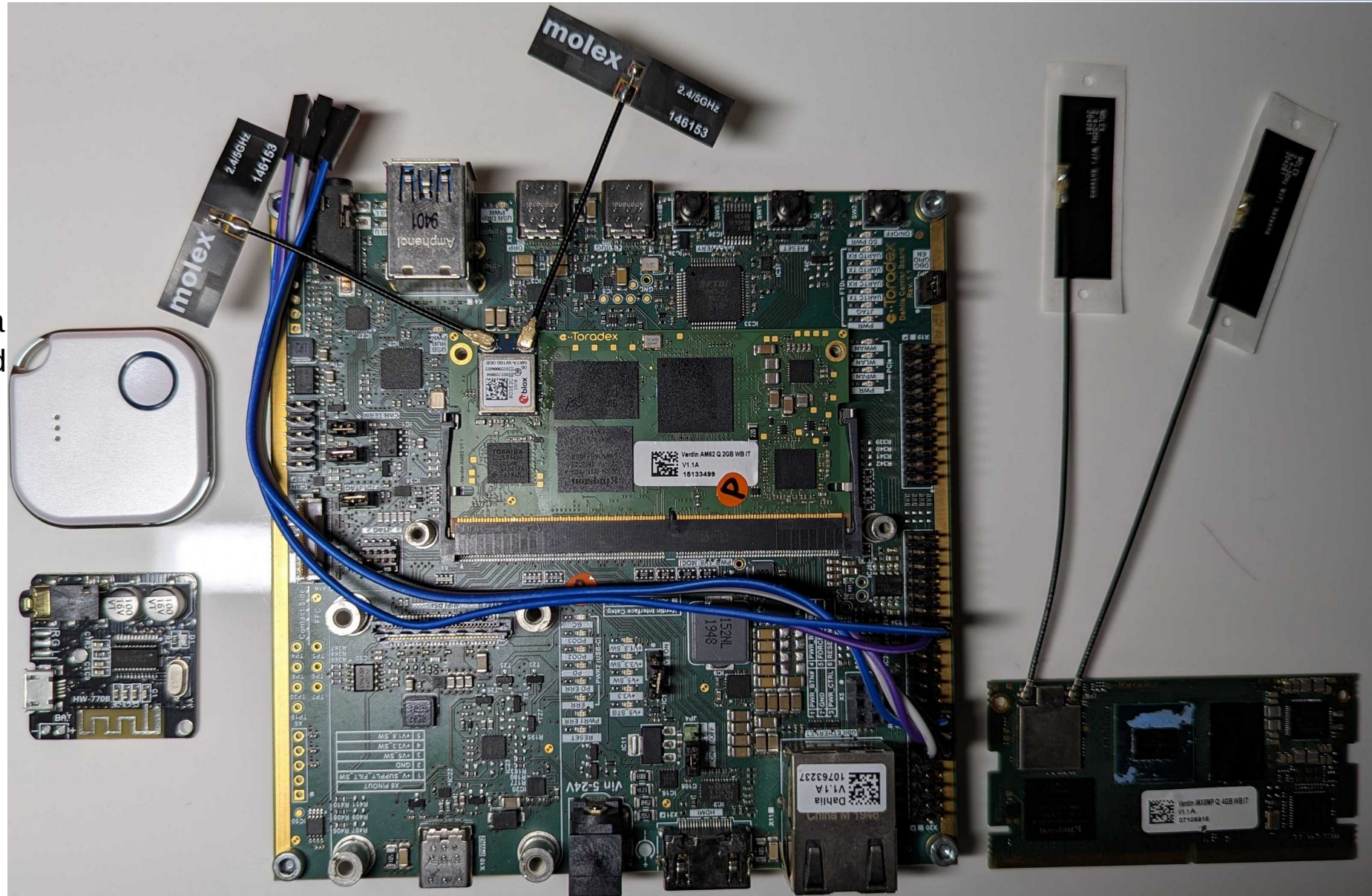
No.	Time	Source	Destination	Protocol	Length	Info
7	5.366212			HCI_MON	7	Sent Adapter Id: 0, Opcode: Control Command
8	5.366434	host	controller	HCI_CMD	9	Sent LE Set Random Address
9	5.366880	controller	host	HCI_EVT	6	Rcvd Command Complete (LE Set Random Address)
10	5.367026	host	controller	HCI_CMD	11	Sent LE Set Extended Scan Parameters
11	5.367494	controller	host	HCI_EVT	6	Rcvd Command Complete (LE Set Extended Scan Pa...
12	5.367731	host	controller	HCI_CMD	9	Sent LE Set Extended Scan Enable
13	5.368287	controller	host	HCI_EVT	6	Rcvd Command Complete (LE Set Extended Scan En...
14	5.368468			HCI_MON	10	Rcvd Adapter Id: 0, Opcode: Control Event

Meld Window:

- Files: .../bt-uart/rx.log and .../bt-uart/tx.log
- Comparison of hex data between the two files, showing differences in the 9th byte (0x00 vs 0x12) and subsequent bytes.

Demo Time

- Shelly BLU Button1
- Bluetooth 5 Audio Receiver Board
- Verdin Dahlia Carrier Board
- Verdin AM62 SoM
- Verdin iMX8M Plus SoM



Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - `hciconfig -a`
 - `rfkill`
 - `rfkill unblock 0`
 - `hciconfig -a`
 - `bluetoothctl`
 - `agent KeyboardOnly`
 - `default-agent`
 - `power on`
 - `scan on`
 - `devices`
 - `pair FD:B2:32:9E:35:80`
 - `connect FD:B2:32:9E:35:80`
 - `exit`
 - `bluealsa-aptplay -l`
 - `bluealsa-aptplay -L`
 - `aptplay -D bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp sound/Gong.wav`
 - `speaker-test -D bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp -c 2 -t wav`

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - TDX Wayland with XWayland Upstream 0.0.0-devel-20240415+build.407 (scarthgap) verdin-am62-15133499 ttyS2
 - Verdin-AM62_Reference-Multimedia-Image-upstream
 - root@verdin-am62-15133499:~# uname -a
 - Linux verdin-am62-15133499 6.9.0-rc4-0.0.0-devel-00005-g2186ca42060f #1 SMP PREEMPT Sun Apr 14 20:38:39 UTC 2024 aarch64 GNU/Linux
 - root@verdin-am62-15133499:~# hciconfig -a
 - hci0: Type: Primary Bus: UART
 - BD Address: 6C:1D:EB:9D:3E:2C ACL MTU: 1021:7 SCO MTU: 120:6
 - DOWN
 - RX bytes:737 acl:0 sco:0 events:43 errors:0
 - TX bytes:467 acl:0 sco:0 commands:43 errors:0
 - Features: 0xbf 0xfe 0x8f 0xfe 0xdb 0xff 0x7b 0x87
 - Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3
 - Link policy: RSWITCH SNIFF
 - Link mode: PERIPHERAL ACCEPT

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image

- `root@verdin-am62-15133499:~# rfkill`
- | ID | TYPE | DEVICE | SOFT | HARD |
|----|-----------|--------|---------|-----------|
| 0 | bluetooth | hci0 | blocked | unblocked |
| 1 | wlan | phy0 | blocked | unblocked |
- `root@verdin-am62-15133499:~# rfkill unblock 0`
- `root@verdin-am62-15133499:~# hciconfig -a`
- `hci0: Type: Primary Bus: UART`
- `BD Address: 6C:1D:EB:9D:3E:2C ACL MTU: 1021:7 SCO MTU: 120:6`
- `UP RUNNING`
- `RX bytes:38948 acl:34 sco:0 events:1829 errors:0`
- `TX bytes:568289 acl:1229 sco:0 commands:125 errors:0`
- `Features: 0xbf 0xfe 0x8f 0xfe 0xdb 0xff 0x7b 0x87`
- `Packet type: DM1 DM3 DM5 DH1 DH3 DH5 HV1 HV2 HV3`
- `Link policy: RSWITCH SNIFF`
- `Link mode: PERIPHERAL ACCEPT`

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - Name: 'verdin-am62-15133499'
 - Class: 0x2c0000
 - Service Classes: Rendering, Capturing, Audio
 - Device Class: Miscellaneous,
 - HCI Version: 5.3 (0xc) Revision: 0x8300
 - LMP Version: 5.3 (0xc) Subversion: 0x1054
 - Manufacturer: Marvell Technology Group Ltd. (72)
- root@verdin-am62-15133499:~# bluetoothctl
- hci0 new_settings: powered bondable ssp br/edr le secure-conn
- Agent registered
- [CHG] Controller 6C:1D:EB:9D:3E:2C Pairable: yes
- [bluetooth]# agent KeyboardOnly
- Agent is already registered
- [bluetooth]# default-agent
- Default agent request successful

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - [bluetooth]# power on
 - Changing power on succeeded
 - [bluetooth]# scan on
 - SetDiscoveryFilter success
 - hci0 type 7 discovering on
 - Discovery started
 - [CHG] Controller 6C:1D:EB:9D:3E:2C Discovering: yes
 - [NEW] Device FD:B2:32:9E:35:80 HW-BT
 - hci0 type 7 discovering off
 - hci0 type 7 discovering on
 - [bluetooth]# devices
 - Device FD:B2:32:9E:35:80 HW-BT
 - [bluetooth]# pair FD:B2:32:9E:35:80
 - Attempting to pair with FD:B2:32:9E:35:80
 - hci0 device_flags_changed: FD:B2:32:9E:35:80 (BR/EDR)

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - `supp: 0x00000000 curr: 0x00000000`
 - `hci0 type 7 discovering off`
 - `hci0 FD:B2:32:9E:35:80 type BR/EDR connected eir_len 12`
 - `[CHG] Device FD:B2:32:9E:35:80 Connected: yes`
 - `hci0 new_link_key FD:B2:32:9E:35:80 type 0x04 pin_len 0 store_hint 1`
 - `[CHG] Device FD:B2:32:9E:35:80 Bonded: yes`
 - `[CHG] Device FD:B2:32:9E:35:80 UUIDs: 0000110b-0000-1000-8000-00805f9b34fb`
 - `[CHG] Device FD:B2:32:9E:35:80 UUIDs: 0000110e-0000-1000-8000-00805f9b34fb`
 - `[CHG] Device FD:B2:32:9E:35:80 ServicesResolved: yes`
 - `[CHG] Device FD:B2:32:9E:35:80 Paired: yes`
 - `Pairing successful`
 - `[HW-BT]# connect FD:B2:32:9E:35:80`
 - `Attempting to connect to FD:B2:32:9E:35:80`
 - `[NEW] Endpoint /org/bluez/hci0/dev_FD_B2_32_9E_35_80/sep1`
 - `[NEW] Endpoint /org/bluez/hci0/dev_FD_B2_32_9E_35_80/sep2`

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - [NEW] Transport /org/bluez/hci0/dev_FD_B2_32_9E_35_80/sep1/fd0
 - Connection successful
 - hci0 type 7 discovering on
 - [HW-BT]# exit
 - root@verdin-am62-15133499:~# bluealsa-aplay -l
 - **** List of PLAYBACK Bluetooth Devices ****
 - hci0: FD:B2:32:9E:35:80 [HW-BT], audio-headset
 - A2DP (SBC): S16_LE 2 channels 48000 Hz
 - **** List of CAPTURE Bluetooth Devices ****
 - root@verdin-am62-15133499:~# bluealsa-aplay -L
 - bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp
 - HW-BT, audio-headset, playback
 - A2DP (SBC): S16_LE 2 channels 48000 Hz
 - root@verdin-am62-15133499:~# aplay -D
 - bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp sound/Gong.wav

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - Playing WAVE 'sound/Gong.wav' : Signed 16 bit Little Endian, Rate 44100 Hz, Stereo
 - ```
root@verdin-am62-15133499:~# speaker-test -D
bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp -c 2 -t wav
```
  - ```
speaker-test 1.2.11
```
 - Playback device is bluealsa:SRV=org.bluealsa,DEV=FD:B2:32:9E:35:80,PROFILE=a2dp
 - Stream parameters are 48000Hz, S16_LE, 2 channels
 - WAV file(s)
 - Rate set to 48000Hz (requested 48000Hz)
 - Buffer size range from 960 to 524288
 - Period size range from 480 to 262144
 - Periods = 4
 - was set period_size = 12000
 - was set buffer_size = 48000

Demo Time (cont.)

- BlueALSA on Verdin AM62 with regular Upstream Tdxref Master Ext Int Image
 - 0 - Front Left
 - 1 - Front Right
 - Time per period = 2.260472
 - 0 - Front Left
 - 1 - Front Right
 - Time per period = 3.000198
 - 0 - Front Left
 - ^CWrite error: -4, Interrupted system call
 - xrun_recovery failed: -4, Interrupted system call
 - Transfer failed: Interrupted system call

Q&A



References

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- Bluetooth Technology for Linux Developers
<https://www.bluetooth.com/bluetooth-resources/bluetooth-for-linux>
- BlueZ
- <https://www.bluez.org>
- MediaTek Filogic 330/360
<https://www.mediatek.com/products/broadband-wifi/mediatek-filogic-330>
<https://www.mediatek.com/products/broadband-wifi/mediatek-filogic-360>
- BlueALSA
<https://github.com/arkq/bluez-alsa>
- Shelly BLU Button1
<https://www.shelly.com/en-ch/products/product-overview/shelly-blu-button1>
- Bluetooth 5 Audio Receiver Board
<https://www.aliexpress.com/item/1005006161260018.html>



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